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Coal ash exposure and asthma in children.

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COAL ASH EXPOSURE AND ASTHMA IN CHILDREN

By

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B.A. University of Louisville, 2014

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ABSTRACT

COAL ASH EXPOSURE AND ASTHMA IN CHILDREN

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This study examined the association between exposure to coal ash in the home among children aged 6-14 and asthma. Data was collected using personal modular impactors, lift tape samples, toe/finger nail samples, questionnaires, and peak flow meters. Laboratory methods used to analyze the samples included gravimetric analysis, scanning electron microscopy (SEM) / energy dispersive x-ray (EDX), and proton-induced x-ray emission (PIXE). Statistical methods used to analyze the data included the Chi Square Test of Independence, logistic regression, the Hosmer-Lemeshow Goodness of Fit test, Fisher's Exact Test, and the Anderson-Darling Normality Test.

Sample size was small, making statistical significance in calculated values unachievable. Though statistical results were not significant, it was suggested that a relationship between asthma risk and exposure was possible. In particular, it was noted that male participants averaged lower peak flow values when compared to the pediatric norm. It was also noted that mean residential distances from the studied power plants were lower in asthma cases than for non-asthma cases. Although results are preliminary and findings were inconsistent, asthma prevalence within the study group was high, compared to the national average in children and requires further study.

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SPECIFIC AIMS

An association between exposure to airborne pollutants and respiratory complications has long been thought to exist (1-3). However, no research has been conducted on the relationship between coal fly ash exposure and asthma in children. Exposure to sufficient amounts of fly ash could potentially have a negative impact on the health of those who are exposed, as fly ash is predominately comprised of particles with diameters less than ten micrometers (PM_{10}) that contain numerous kinds of harmful metals which are readily absorbed into the body through inhalation (4, 5). This preliminary study evaluated whether there was an association between fly ash exposure and asthma prevalence in children living within the study area.

To achieve this goal, the following specific aims were evaluated:

1. To determine if a relationship exists between asthma occurrence and exposure to fly ash within multiple communities located within ten miles of two Louisville Gas and Electric (LG&E) power plants located in Louisville, Kentucky.
2. To determine if household exposure to toxic metals found in PM_{10} was associated with asthma prevalence.
3. To determine if residential proximity to the coal-burning power plants was associated with asthma prevalence.

The methods utilized within this cross-sectional study closely follow those of the Coal Ash Exposure and Neurobehavioral Symptoms in Children Aged 6-14 Years Old study, funded by the National Institutes of Environmental Health Sciences (R01ES024757, PI Zierold). Exposure analysis involved the use of personal modular impactors, environmental particulate air monitors (EPAMs), lift sampling, toe and finger nail sampling, and questionnaires to gather the required data. In addition, peak flow meters were utilized to provide supplemental data to the responses reported on the administered respiratory health questionnaire. Geographic Information Systems (GIS) analysis was utilized along with gathered data to evaluate the association between residential proximity and exposure.

INTRODUCTION

Description of Coal Ash

Coal ash is the general term for the various byproducts of coal combustion; these byproducts include fly ash, bottom ash, boiler slag, flue gas desulfurization (FGD) waste, and fluidized bed combustion (FBC) waste (6). Fly ash is a fine form of particulate matter that is capable of being lifted out of coal plant smokestacks by exhaust gases produced during the combustion process. It is a form of particulate matter, PM_{10}, which is easily transported through the air and is readily inhaled and absorbed into the bloodstream (7, 8). Most fly ash that is produced is captured in air pollution control devices, such as baghouses; the ash is then transported to landfills and storage ponds.

Fly ash can be recycled and used for a variety of purposes, including the manufacturing of concrete and cement, as a structural fill or embankment, as a waste stabilizer, and for mining applications (9). In 2014, a total of 50,422,238 short tons of fly ash were produced through coal combustion (9); in comparison, only 23,181,723 short tons of this fly ash were beneficially recycled and utilized, resulting in a large amount of fly ash being stored in landfills and ponds, many of which aren't properly proofed against seepage into the surrounding environment.

Coal Ash in Kentucky

LG&E is an electric and natural gas providing corporation that serves Louisville, Kentucky and sixteen other surrounding counties (10). In total, LG&E provides electricity to 407,000 customers and natural gas to 324,000 customers. The LG&E service area spans an estimated 700 square miles. In Louisville, electrical power generated by the corporation's two primary power plants, Cane Run and Mill Creek, is predominately derived from the combustion of coal and natural gas.

As per the 2007 Environmental Protection Agency (EPA) risk assessment, LG&E utilizes two landfills and three ponds for the disposal of coal ash generated by the Louisville area plants (11). According to this risk assessment, there were a total of forty-six coal ash landfills and ponds in the state of Kentucky; ten of these were unlined, and of these unlined sites, eight had no leachate collection systems and five lack groundwater monitoring systems. By definition, leachate is water that has percolated through a solid, drawing out some of its constituents in the process, or in this particular case, the liquid that drains from a landfill. Unlined landfills and ponds lack the low permeable composite liners that are meant to prevent potentially toxicant-containing leachate from entering the soil and ground water. Kentucky alone creates over nine million tons of coal ash per year, making it fifth in the nation for coal ash generation.

Cane Run Power Plant

The Cane Run generating station began operation in 1954 (12). Located less than a quarter mile from the banks of the Ohio River in southwestern Louisville, this facility spans an estimated 500 acres and houses several ponds, including one large, forty acre pond designated for the collection and treatment of coal ash (13). This pond – the Ash Treatment Basin (ATB) – and its accompanying dam have been granted a high hazard potential rating by the EPA, meaning that should the structural integrity of either construction be compromised, loss of human life would likely occur (13, 14).

The Cane Run power plant also houses a landfill predominately used for the storage of coal-combustion derivatives, including coal ash (15). This landfill spans an area of approximately 110 acres, stands 130 feet high, and is partially uncapped – it is open to the air. Concern regarding the landfills has been reported by residents to the local media (16).

The Cane Run power plant was a coal-burning facility for the majority of its life (12). In July of 2015, the plant was converted to a natural gas-combusting facility, thus ending the use of coal as an electricity generating source (12). Despite the elimination of further coal ash production, the existing ash storage sites continue to exist. The ATB is slated to be drained and filled by 2018, but the ash landfill has yet to have an official timeline established for capping and decommission (15).

Mill Creek Power Plant

The Mill Creek generating station began operation in 1972 and spans 544 acres adjacent to the Ohio River in southwestern Louisville (17). Mill Creek is LG&E's largest generation station powered by coal and has a generation capacity of 1,472 megawatts. One large coal ash storage pond is housed on site, taking up approximately 43 acres (18). This pond and its embankments have been given a high hazard potential rating by the EPA, suggesting that loss of life and significant property and project operations damage could occur should structural failure occur (18).

The Mill Creek power plant also houses a dry landfill primarily purposed with the storage of coal-combustion byproducts, including coal ash (17). This storage site is uncapped and unlined, suggesting that the risk for environmental contamination is present for the surrounding area (19).

In order to comply with the EPA regulations that became effective in 2015, LG&E has announced plans to cap and close its coal ash storage pond at the Mill Creek plant (20). The site's ash landfill remains active and no plans for decommission have been announced as of 2017.

Fly Ash and Potential Health Problems

It has been demonstrated that coal fly ash is a very real exposure for those who work in jobs where coal combustion occurs (21). A study published in 2015 by Zeneli et al. examined the relationship between fly ash and how it affected the antioxidant defense systems of power plant works in Kosovo (21). A total of 97 adult male participants were selected, 70 were power plant workers and 27 were healthy inhabitants of the Dragash rural municipality, a location considered to be relatively free of air pollution. Each participant responded to a questionnaire including occupational exposure duration and medical history, and had a venous blood sample drawn. Analysis of these blood samples revealed that the power plant workers had mercury blood levels 4.3 times higher and arsenic blood levels 1.7 times higher compared to the control group. Power plant workers also demonstrated potentially hazardous alterations to antioxidant concentrations and activity in their blood.

There are documented cases of fly ash found on residential sites surrounding a power plant where coal combustion occurs and where coal ash is stored (22). The RJ Lee Group was commissioned by LG&E in 2011 to evaluate surface dust samples gathered from three houses near the Cane Run power plant (22). The RJ Lee Group provided adhesive lift samplers – lift tape – to LG&E staff, who collected six samples from each home and sent them to the RJ Lee Group for analysis. Analysis via scanning electron microscopy (SEM) revealed that fly ash was present on each sample gathered, indicating some level of exposure.

Metals

Fly ash is known to contain many potentially toxic metals, and is therefore thought to be a major threat to public health (4). The metallic composition of fly ash varies depending on the location from which the source coal was mined, but there are certain substances that were consistently found regardless of location. Though certainly not the only elements present, the following are known or suspected toxicants found in fly ash: arsenic, boron (a metalloid), chromium, lead, manganese, and mercury (4, 23, 24). These elements, often found in fly ash, are capable of causing significant health complications when associated with sufficient concentration including debilitating respiratory effects (24, 25).

A study published by George et al. in 2014 showed that the soils surrounding coal-fired power plants can be affected by the byproducts produced through the coal combustion process (26). Elements including arsenic, chromium, and mercury were found in greater concentrations in soil samples taken from around the Santaldih power plant in West Bengal, India than from control samples taken from a remote site in the region, and most were shown to have originated from emissions produced by the plant. It was also noted that young children were most susceptible to exposure to these elements. Though the soil levels of these elements were technically within safe levels for human health risk, this study demonstrated that the byproducts of coal combustion can linger and accumulate in the environment, increasing risk for exposure.

Metals and Health Effects

Arsenic ingestion, as through contaminated water or other sources, has been linked to nervous, cardiovascular, and urinary tract complications (27). Inhalation of arsenic has been linked to lung cancer and other respiratory issues. These issues range from chronic obstructive pulmonary disease to bronchitis, and have been observed in populations all around the world, including Bangladesh, Mongolia, and Chile (28). An examination of data, conducted by Parvez et al., derived from a study carried out in Araihazar, Bangladesh examined the relationship between consuming arsenic-contaminated water and respiratory problems in the local population (28). Data from the Health Effects of Arsenic Longitudinal Study (HEALS) were utilized for analysis and were based on a cohort of 11,746 adult participants recruited from 2000 to 2002. Each participant provided demographic and lifestyle data as well as water and urine samples at baseline and at every two-year follow up for the duration of the study. Those with self-reported preexisting respiratory symptoms were excluded at baseline; respiratory symptoms that developed during the study duration were defined as being the development of a frequent cough that last over three months, difficulty breathing, and/or having a cough that produced blood. Sixteen percent of the cohort was determined to have developed a respiratory symptom during the study, and analysis revealed positive significant associations between arsenic exposure and the development of these symptoms.

Chromium inhalation can cause asthma, wheezing, and lung cancer (29, 30). Hexavalent chromium, also known as chromium (VI), is form of chromium noted as being particularly harmful to the respiratory tract and also as being carcinogenic (31).

Those most frequently exposed to chromium (VI) are workers in environments where chromium-containing products are found, such as welders, and those living near uncontrolled hazardous waste sites containing chromium (31). A clinical study conducted by Cerveira et al. in 2014 noted that lab grown human bronchial epithelium cells exposed to a chromium (VI) concentration – one micro molar over 48 hours – comparable to that of the chromium (VI) concentration found in lung cancer-suffering chromate workers' peripheral lung tissue have a tendency to reveal enhanced aerobic glycolysis, a metabolic characteristic found in cancerous lung cells (32).

Though not known to be overtly carcinogenic, manganese and boron have nevertheless been found to hinder healthy respiratory function (33, 34). Manganese can cause lung irritation and lead to an inflammatory response in the lungs when present in certain compounds and in high concentrations (34, 35). Boron inhalation can irritate the eyes, nose, and throat (33, 36). There were proponents for boron as a beneficial supplement to human nutrition, but even these individuals note that excessive airborne exposure can cause debilitating respiratory symptoms (37).

Mercury can have a devastating impact on neurological development and on the nervous system in general, and can cause lung damage when inhaled in vapor form (38-40). A case report published by Lien et al. in 1983 examined the effect of accidental mercury vapor inhalation by four adults and three children, as well as how these instances could be related to similarly reported cases (40). It was noted that mercury vapor is a direct airway irritant, and that inhalation can produce a cough, labored breathing, chest pain, and rapid breathing.

Lead has not been correlated with respiratory complications to date, but is known to produce devastating symptoms in other systems of the human body (41). Lead is highly toxic when ingested or inhaled, and exposure can result in a variety of neurological, circulatory, and cardiovascular disorders (41).

Asthma

Asthma is a chronic disease of the lungs characterized by constant inflammation and trigger-induced tightening of the airways. Symptoms often include coughing, chest tightness, shortness of breath, and wheezing. A common trigger of asthma symptoms is physical activity, though other triggers can come in the form of dusts, fumes, gases, and other substances inhaled under a variety of circumstances. In the United States, approximately 7.4% of adults and 8.6% of children are reported to have asthma (42). Despite there being ways to manage and treat asthma symptoms, there is no cure for this disease. It is estimated that 300 million people are afflicted with asthma worldwide, and 250,000 annual deaths can be attributed to it (43).

There have been clinically documented cases where asthma and asthma-like symptoms have been induced by exposure to airborne pollutants (24, 43). Though only reflecting data derived from a single individual, a study published in the British Medical Journal in 1986 reported a possible association between asthma and coal ash exposure (24). It was documented that a worker at a power plant began to develop shortness of breath and wheezing after nine months of working in an environment where coal ash exposure was routine. This same worker was admitted to the hospital on several occasions for acute severe asthma. The worker's peak expiratory flow rates were measured every two hours for 28 days, revealing that the severity of his symptoms were considerably greater while at work. The worker was eventually relocated from the exposure-prone position after it became clear that his work was detrimental to his health, whereupon his symptoms rapidly disappeared.

Thorough literature analysis reveals that there is a clear relationship between both the development of asthma and asthma-like symptoms and the exacerbation of existing symptoms by exposure to PM_{10} (5, 7). An extensive meta-analysis conducted by Weinmayr et al. based on 36 studies reported an association between PM_{10} and asthma occurrence (7). The meta-analysis determined the existence of this relationship by extracting quantitative PM_{10}, respiratory symptom, and peak expiratory flow data from the included studies and analyzing it for significant associations. The included study populations were primarily from Europe and the United States, and season was found to have a modifying effect. Given that this relationship has been shown to exist and that coal fly ash is a form of PM_{10}, it is reasonable to suspect that populations exposed to this form of air pollution may be at greater risk for asthma and asthma-like symptoms.

Asthma in Louisville

Louisville, Kentucky has been ranked among the top 100 worst cities in the United States for those suffering from asthma (44). Research has shown that the highest asthma rates are seen in western Louisville, and that racial disparities exist, with higher rates being seen in African American populations. It has also been demonstrated that there is seasonality to asthma rates in Louisville, with a peak in autumn and a trough appearing in the summer.

Children and Asthma

In the United States, approximately 8.6% of children are reported to have asthma (42). Asthma is the third leading cause of hospitalizations among children (44). It was been hypothesized that children are more likely to be seriously affected by environmental toxicants than adults because they are still in the process of growth and development. Their behaviors also put them at greater risk; hand/mouth behaviors, being closer to the ground, playing in the dirt and grass, and breathing more all increase potential exposure to environmental toxicants (45-47). Since fly ash is PM_{10}, and because of the above mentioned reasons, those children that live within potential exposure proximity to the Cane Run and Mill Creek Power Stations may be at elevated risk for asthma development if coal ash is found to be in their homes.

GIS and Asthma

GIS is a computerized mapping and analysis technology that allows for the analysis and visualization of data as it pertains to geography (48). GIS is capable of manipulating large amounts of data, thus allowing it to be used to conduct analysis at the local, regional, and national level. Given the fact that asthma is a disease spread across a wide range of geographic areas and is attributable to many different risk factors, GIS is a valuable tool for conducting research pertaining to asthma (43, 48). Among other things, GIS can be used to map proximity to known or suspected sources of disease risk factors, making it useful for determining patterns in disease distribution.

An example of a GIS-based approach to studying asthma can be seen in a study published in 2014 by Gorai et al (43). Exposure to air pollution, including $PM_{2.5}$, is known to be associated with elevated asthma risk. The study used GIS to map asthma hospitalizations and air pollution data for the state of New York. Asthma hospitalization data were gathered from New York State's Asthma Surveillance Summary Report, 2009. Air pollution data were gathered from the US EPA Air Quality System by means of 72 New York based monitoring stations over the course of three years, from 2005 to 2007. The maps created using GIS showed the spatial distribution of asthma rates and air pollution based on varying concentrations of SO_2, O_3, and $PM_{2.5}$. The association between air pollution and asthma was established by comparing asthma rates to extracted air pollution concentration data for each county. The results revealed that asthma is significantly associated with increased concentrations of SO_2 and $PM_{2.5}$.

Measurement of Asthma

Asthma can be a difficult disease to detect without the use of accurate screening methods. Questionnaires, while useful for surveillance, can have low specificity, producing large numbers of false positive results (6). In order to capture a more exact picture of asthma prevalence within a population, it is necessary to implement methods that can fine tune the results of these questionnaires. In 2002, a multi-stage asthma screening procedure was developed, tested, and published by Gerald et al. in the *Journal of Asthma*, providing a solution to the issues posed by questionnaire-reliant screening methods(6).

Gerald et al. proposed the use of a three step screening procedure composed of a questionnaire, spirometric analysis, and an exercise challenge test (6). The questionnaire allowed for classification of participants as being previously diagnosed with asthma, showing no evidence of asthma, and suspected of having asthma. The spirometric analysis involved the gathering of three forced vital capacity (FVC) values from participants who were suspected of having asthma; those who were found to have a forced expiratory volume (FEV) / FCV ratio of less than 80% were considered as being highly suspect of having asthma, and were referred to a physician for confirmation of disease status. Those participants who had an FEV / FCV ratio of greater than or equal to 80% were asked to complete a submaximal exercise challenge test, involving stepping up and down on a single step for a duration of time and the subsequent measurement of pulmonary activity following completion. Participants who showed a greater than 15% decrease in average FEV were referred to a physician for confirmation of potential disease status.

In Gerald et al.’s study, the implementation of the three step screening procedure reduced the questionnaire-only asthma prevalence rate from 32% to 9.89% (6). The suspected asthma diagnosis determined by the screening procedure was confirmed in 96% of participant children who saw the physician they were referred to. In 2004, Gerald et al. sought to further validate the three step screening procedure by conducting a study designed to determine the sensitivity, specificity, and predictive value of the three step procedure, as well as the procedure minus the exercise test – called the two step procedure (49). The full three step procedure was found to have a sensitivity of 82%, specificity of 93%, and predictive value of 93%. The two step procedure was found to have a sensitivity of 78%, specificity of 93%, and predictive value of 93%. The questionnaire alone, when using a narrow definition for probable asthma diagnosis based on a combination of answers provided by the participant, had a sensitivity of 66%, specificity of 96%, and a predictive value of 95%. The predictive values found in the study population were thought to be higher than those that would be found in the general population, as the study population was relatively small and had a high prevalence of asthma.

Peak Flow Meters

In this study, the primary instrument of choice for determining participant asthma status was the Mini Wright peak flow meter, as manufactured by Clement Clarke International. The peak flow meter's function is to determine the peak expiratory flow rate of the individual blowing into it (50, 51). Peak expiratory flow rate is the rate of air expired from the large airways within an estimated 100 to 120 milliseconds of the start of forced expiration; expiration in this manner remains at a peak for approximately 10 milliseconds. This parameter has been noted as being highly useful in monitoring the respiratory status of individuals, particularly when evaluating for asthma (50). Peak expiratory flow can vary depending on several factors, including height, weight, gender, age, and environmental conditions (50, 51).

METHODS

This study was a sub-study conducted in tandem with the National Institutes of Health (NIH) funded Coal Ash Exposure and Neurobehavioral Symptoms in Children Aged 6-14 Years Old study lead by principal investigator Kristina Zierold, PhD – (R01E024757). The ongoing parent study's objectives were to evaluate the association between environmental exposure to coal ash and the development of neurobehavioral symptoms in children and to investigate if there are differences based on distance from the power plants. The objective of the current sub study was to evaluate the association between environmental exposure to coal ash and the development of asthma and asthma like symptoms in children. Much of the same data was utilized between the two studies, though study-specific data was gathered as necessary.

This cross-sectional study made use of a diverse array of data collection technologies, thus allowing for the establishment of an accurate representation of the relationship that existed between coal ash exposure and respiratory health in children. Personal modular impactors, EPAMs, lift samples, toe and finger nail samples, questionnaires, and peak flow meters were all used, as each method provided vital and unique data. The use of multiple different pollutant detection technologies and methods allowed for adequate quality control.

Study Area

The study area was located exclusively in Louisville, Kentucky. Five buffer zones each of which represented a two mile interval were generated from a centroid, which was the midpoint between the Cane Run and Mill Creek power plants. The buffer zones represented ≤2 miles, >2-4 miles, >4-6 miles, >6-8 miles, and >8-10 miles. Once the buffer zones were established, they were divided into quadrants. In total, there were 20 quadrants. For example, quadrant 1A represented a quadrant north of the centroid that was ≤2 miles from the centroid. See Figure 1.

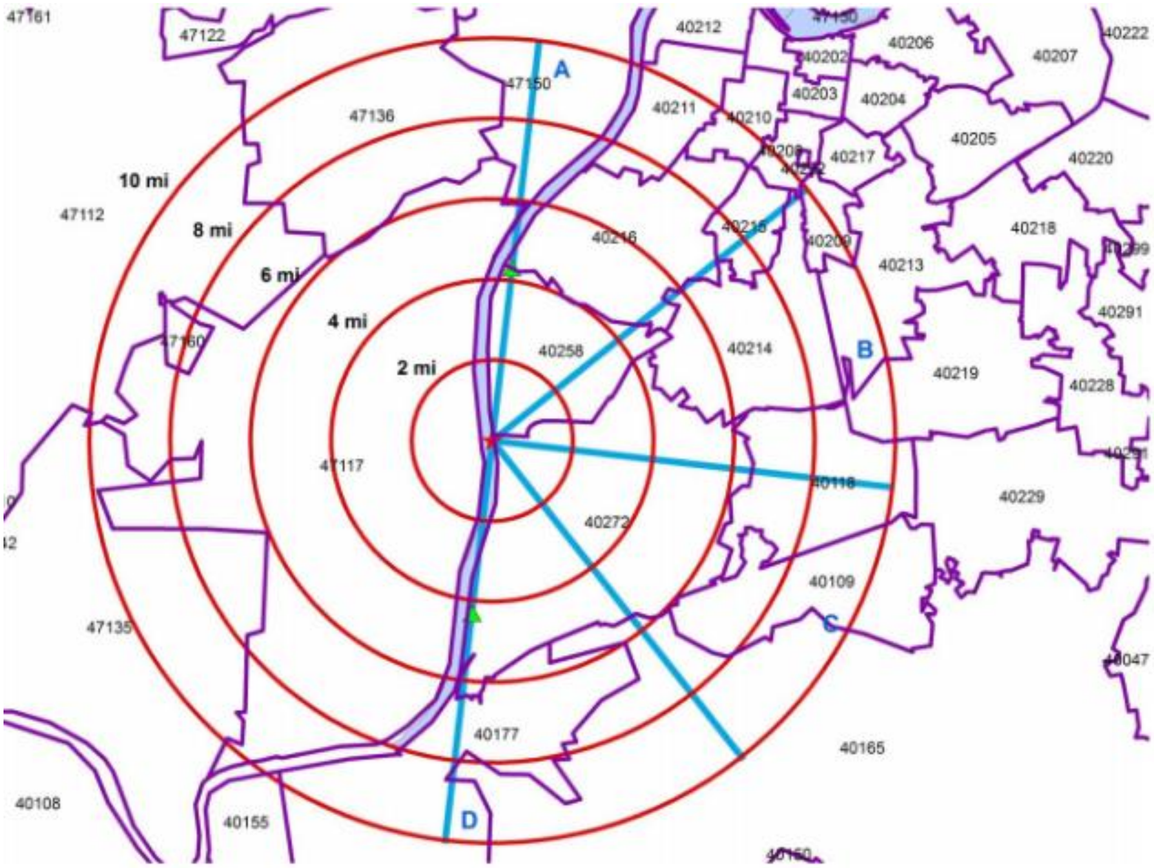


Figure 1 – Buffer Zones of the Study Area

Participants

Participants were children between the ages of six and fourteen and at least one parent or guardian living within the designated twenty study quadrants located predominately in southwest Louisville. Participants lived in Kentucky zip codes 40155, 40177, 40165, 40109, 40272, 40118, 40219, 40214, 40213, 40258, 40216, 40209, 40215, 40210, 40211, and 40208. The ongoing parent study will include a total of 300 children and one parent or guardian per child. For this sub-study, 27 children and one of their parents or guardians participated. All field data was gathered from the homes of participants whose parents or guardians elected to take part in the study.

Eligibility criteria included being of age 6-14 years, residency in the study area for a minimum of two years, consent for a week of uninterrupted air sampling, completion of all questionnaires and an in-home environmental health assessment, completion of a pediatric health history and data collection of the child's pediatric health history by a community nurse, neurobehavioral performance tests administered by the team's child psychologist, and consent to conduct peak flow meter readings. Children were excluded from the study if there was reported evidence of a known genetic disorder that affected neurological functioning, or if the parent(s) of the child refused to smoke outside the home.

Recruitment

Participants were recruited primarily through door-to-door flyer distribution within the included study quadrants, or through the use of mailing lists. While going door-to-door, property restrictions were respected at all times; for example, houses with "no trespassing" or "no soliciting" signs were not included in the flyer distribution process. Study personnel did not enter a participant's home alone, and were instructed on safety precautions and were provided with first aid kits while in the field.

The study was approved and conducted under the University of Louisville's Institutional Review Board (IRB) protocol. Recruitment occurred from January 2016 until July 2016; 27 children and one of their parents were recruited to take part in the asthma study. After the participants were consented and assented for the main study, a preamble was provided to the participants that described the asthma study.

Analysis Methods

Several different methods were utilized to analyze the samples collected over the course of the study; these methods included gravimetric analysis, proton-induced X-ray emission (PIXE) analysis, and scanning electron microscopy (SEM) / electron dispersive x-ray (EDX). Each of these methods was used in accompaniment with a corresponding exposure assessment technique, which was discussed in the following section.

Gravimetric Analysis on Filters

Gravimetric analysis is a technique that allows for the amount of a particular element present in a sample to be determined via the measurement of mass. In this particular study, the mass of a filter was recorded both before and after it was placed within an impactor, allowing for the mass of PM10 collected to be calculated. Flow rates – in liters per minute – were recorded and averaged. This data allowed for the calculation of PM10. Once the mass of the PM10 was determined, the filters were sent to Elemental Analysis Inc (Lexington, KY) for additional elemental analysis, called Proton Induced X-ray Emission (PIXE).

PIXE Analysis on Filters

PIXE analysis is a form of X-ray spectrographic technique that can be utilized to analyze the composition of a sample without causing damage to it (52). PIXE analysis can be utilized for all types of samples, including aerosol filter samples, making it an ideal analysis method for this study. The sample is bombarded by a stream of protons, exciting the inner shell electrons of the target atoms. When the inner shell electrons were excited and expelled, they produce X-rays; these X-rays are produced in specific quantities and energy levels that uniquely correspond to particular elements, thus identifying the elemental composition of a given sample. PIXE provides concentrations for 72 elements from the periodic table, sodium through uranium.

PIXE Analysis of Toe/Finger Nails

In addition to being used on filters, PIXE analysis was used to determine the composition of toe and finger nail samples. The preparation procedure requires that the nails were washed in acetone, rinsed twice in de-ionized water, allowed to dry, and re-weighed. The nail samples were then sent to Elemental Analysis Inc, where they were frozen with liquid nitrogen and ground, milled, mixed with a paint binder, and pressed flat into an easily analyzed pellet. Approximately 100 to 200 milligrams of nails were required per participant in order to create a pellet of sufficient size.

SEM-EDX on Lift Samples

In addition to the filters, lift samples were used and analyzed by optical microscopy (OM) and scanning electron microscopy / energy dispersive using x-ray (SEM-EDX). OM works by utilizing visible light and lenses to magnify images of samples. If fly ash particles were deemed present through the usage of OM, the samples were analyzed via SEM/EDX. SEM works by focusing a beam of high-energy electrons on the surface of a provided sample, which in turn produces several different signals that can reveal such information as sample morphology, structure, and composition (53). The data gathered from the signals was interpreted by the SEM instrument, which then provides a two-dimensional image of the area of the sample being analyzed. Conventional SEM can provide images of areas ranging from roughly five microns to one centimeter. SEM was particularly useful for this study because of its ability to provide highly magnified images of small particles; once properly magnified, fly ash particles were very easily identified amongst other particles, as they had a unique, spherical shape. EDX was used to determine the elements in the individual fly ash particles.

Exposure Assessment

Study personnel arranged the impactors and EPAMs in the homes of participants. Each of these devices independently assessed the composition of the air within the household. The devices were set up in the most frequently used room by the participant and their family, usually the main family room or den. The EPAM provided continuous, direct data on the air quality within the household. It was set to detect PM_{10}. The impactor drew air in, catching particulate matter on a filter, which was later removed and delivered to Elemental Analysis Inc. for PIXE analysis. Both the EPAM and air sampler impactor were set to run for one week, as this was the minimum time deemed necessary for adequate sample data to be gathered. Ideally, the impactors ran at a flow rate of three liters per minute, on average, and were inspected periodically to ensure that they did so.

Three or four lift samples were gathered at the time of equipment setup. These lift samples were taken from the room in which the participating child slept. When taking lift samples, it was generally considered best to take one from the participant's bed, one from a window sill in the participant's room, and one from objects commonly made use of by the participant, such as favorite electronics or desks. Lift sample locations were recorded in the designated study notebook each time they were taken; for example, if lift sample 1A was taken from the participant's headboard, the sample location was recorded under participant number one as A – headboard. If a fourth or fifth lift sample was ever used, it served as a blank; blanks were used for approximately every tenth participant. The lift samples were delivered to EAI for OM and SEM-EDX analysis once they were gathered.

Toe and finger nail samples were first gathered from each participant at the time of consent. The clippers used to gather the samples were provided by the consenter or accompanying study staff. The participant either clipped their nails themselves or had a parent or guardian do so. A total of one hundred and fifty milligrams or greater are required from each participant.

Given the relatively light nature of the samples being gathered, additional nail gatherings were required beyond the initial sample. In general, four to six clippings were required. These nail clippings were picked up from the participant's parent or guardian at pre-arranged times, as needed. The nail samples were left in the mailbox and the study team picked them up bi-monthly. Containers were provided for the collection and storage of nail samples and containers were identified with only the participant study number.

Questionnaires

Four questionnaires were utilized to gather lifestyle, environmental health, and general health data about the participating child from the participant's parent or guardian. The questionnaires utilized included the following: a seven day twenty-four hour activity diary, the child behavior checklist, an environmental health history questionnaire, and a home cleaning questionnaire.

For this sub-study, a child respiratory health questionnaire was used to record the presence or absence of asthma as self-reported by the participant or participant's parent or guardian. Supplementary data concerning environmental factors was also collected for the present study. These supplementary factors included whether or not any individual smoked in the household, if the home's air filters were regularly replaced, and if more dust than was considered normal was noted in the home. Normal level of dust was based upon the opinion of the participant. The child respiratory health questionnaire was based on a similar screening test developed by Gerald et al (6).

Ideally, all questionnaires were gathered at the same time as when the air sampler impactor and EPAM were picked up. De-identified data, except for addresses when necessary were entered into secure computerized databases. All questionnaires were stored in a locked file cabinet within the principal investigator's office unless being utilized for data input.

In addition to the questionnaires that were left for the participant's parent or guardian to complete, a child health history and home exposure assessment were completed by the study nurse based on an interview with the parent or guardian. These documents were used to supplement data needed to assess the study outcomes.

Asthma Measurement in the Coal Ash Exposure and Asthma in Children Study

The questionnaire utilized in the *Coal Ash Exposure and Asthma in Children* study was very closely modeled, with acquired permission, after the questionnaire developed in the 2002 Gerald et al. study (6). This questionnaire was found to be quite reliable (49), especially when paired with the use of spirometry, and therefore seemed to provide an ideal template. Spirometric analysis in the Gerald et al. studies was conducted using a Multispiro spirometer (6). FEV values in the *Coal Ash Exposure and Asthma in Children* study were gathered through the use of Mini-Wright peak flow meters. These peak flow meters provide valid FEV for participant assessment with use of the proper technique. The resulting FEV values were paired with pediatric norms to determine presence or absence of asthma (54).

Asthma Specific Questionnaire

The asthma specific-questionnaire consisted of fifteen multiple-choice questions. An asthma diagnosis was based on the scale utilized in the Gerald et al. study (6)(see Appendix A). The participant was considered to be free of asthma symptoms if the questionnaire revealed and of the following responses: all “no” answers, “yes” to question two only, “yes” to question four only, “yes” to question ten only, or “yes” to questions two and ten only. Previous asthma was diagnosed if the questionnaire revealed “yes” answers to both questions seven and eight. Suspected undiagnosed asthma was reported with any other combination of answers – excluding answers to questions thirteen through fifteen, as these provided information concerning environmental factors. For the purpose of dichotomization, those who fell under either the previously diagnosed asthma category or suspected undiagnosed asthma category were simply reported as having asthma.

Peak Flow Meters

Peak flow meters were utilized synergistically with the child respiratory health questionnaire to assess asthma. Peak flow meters measured peak expiratory flow and are affected by the gender and height of the child participating. After the parent was consented and the child assented, peak flow measurements were taken. A study team member demonstrated the use of the peak flow meter to the child and encouraged the child. Children were told to stand up straight, with their feet apart, and blow as if they were blowing out candles on a birthday cake, as hard as they could. Three separate measurements were recorded, with the highest recorded as the overall peak flow score; if the participant showed signs of respiratory distress or abstained from multiple measurements, two separate measurements were taken and the highest was recorded as the overall peak flow score. For reasons of hygiene, the participant was allowed to keep the peak flow meter following its use. Peak flow measurements were recorded in a notebook expressly designated for this purpose, which was kept secure in the study laboratory when not in use. Peak flow measurements were compiled into a computerized database for statistical analysis after they were gathered.

STATISTICAL/GIS METHODS

Each of the three specific aims outlined previously in the paper required unique methods for attaining desired results from gathered data. The main statistical methods used to analyze these aims were the Chi Square Test of Independence, logistic regression, the Hosmer-Lemeshow Goodness of Fit test, Fisher's Exact Test, and the Anderson-Darling Normality Test (55). The Chi Square Test of Independence is a test utilized to determine if there is significant association between two categorical variables derived from a given population. Logistic regression is a statistical method used to analyze the effect of an independent variable or variables on dichotomous outcomes within a dataset. The Hosmer-Lemeshow Goodness of Fit test is a test that defines the goodness of fit within logistic regression models – goodness of fit being the degree to which observed outcomes match theoretical outcomes. Fisher's Exact Test is a significance test used to analyze contingency tables, and is typically more useful than the Chi Square Test of Independence when population sizes are small. The Anderson-Darling Normality Test is a test used to determine if a given dataset is representative of a given probability distribution – if it is normal.

The first aim, "to determine if a relationship exists between asthma occurrence and exposure to fly ash," required that two variables be dichotomized: presence of fly ash on filters (yes/no) and asthma diagnosis in participant (yes/no). The presence of fly ash on lift tape samples was noted by the number of samples per participant that were found to contain fly ash. Once the variables had been dichotomized for all participants, the Chi-

Square test of Independence was used to determine if there was a significant relationship between disease and exposure. Additionally, a prevalence odds ratio was determined using logistic regression, partially explaining if asthma can be related to fly ash exposure. The final models used were determined based on the results of Hosmer-Lemeshow Goodness of Fit tests, as other modeling methods might be questionable due to small sample size.

The second aim, "to determine if household exposures to toxic metals found in PM_{10} were associated with asthma, should fly ash be detected," required that individual metals found within gathered filter samples be scored based on whether or not they were present and associated with fly ash. The variables representing the presence of a given toxic metal were dichotomized as either yes or no. A metal score was created based on the number of metals present. The same modeling methods were used as for the first aim.

The third aim, "to determine if residential proximity to the Mill Creek and Cane Run Power plants was associated with asthma prevalence," required the use of Geographic Information Systems software – ArcGIS was used for this study. Proximity was measured as being either "near," within five miles of the power plant under examination, or "far," between five and ten miles of the power plants; the "far" category was treated as the control, as closeness to the power plants was hypothesized to be associated with greater asthma risk. More exact categories based on single mile increments were attempted, but due to small sample size, the results were inconclusive. Participant addresses were geocoded to a street map overlaid on a map of Jefferson County, which also included the locations of the Mill Creek and Cane Run power plants, as well as relevant dump sites. The map was projected in feet using the projected state plane coordinate system NAD 1983 2011 Kentucky North FIPS 1601 Ft US. The geocoding process required only an Excel spreadsheet containing necessary address data and the creation of an address locator in ArcGIS. The resulting maps provided information concerning the distribution of asthma and non-asthma cases across the study area.

The ArcGIS "near" function was utilized to determine and record the distance of each address from both power plant locations by selecting each address shape file as the "input" feature and each plant shape file as the "near" feature, and then running the function for each shape file combination. Results reflected distances in feet, and were recorded in generated attribute tables. These attribute tables were exported into Microsoft Excel for statistical analysis.

RESULTS

In the following sections, the results corresponding to each of the previously mentioned specific aims are presented. The total sample population for this study was 27 participants; however, some had missing data, and thus the sample sizes vary.

Aim One

Table 1 reports the demographics of the sample used. Overall the sample was 54.1% male, with a mean age of 10.69 years of age. Only 2 participants reported smoking in the home. Toxic metals commonly found in the lift samples or filters included arsenic, chromium, and manganese. Table 2 provides the highest peak flow and the average peak flow values for the participants. The median peak flow value for males was 300 L/min and 250 L/min for females. Peak flow measures were standardized by gender, age, and height.

Table 1 **Demographic Frequencies**			
	Male (13)	Female (11)	Total (24)
Age (years)			
Mean	11.77	9.41	10.69
Height (in)			
Mean	61.96	53.98	58.30
Median	65.50	54.50	54.50
Smoke in Home			
Yes	1	1	2
No	11	10	21
Participants with Metals on Filters	2	3	5
Arsenic Found			
Yes	5	3	8
No	8	8	16
Manganese Found			
Yes	8	7	15
No	5	4	9
Chromium Found			
Yes	3	1	4
No	10	10	20
Metal Score			
0	2	3	5
1	7	6	13
2	3	1	4
3	1	1	2

Table 2 Peak Flow Information		
	Male (13)	Female (11)
Highest Peak Flow Value (L/min)		
Lowest	220.00	150.00
Highest	440.00	480.00
Median	300.00	250.00
Average Peak Flow Value (L/min)		
Lowest	193.33	140.00
Highest	430.00	443.33
Median	290.00	223.33

The median heights for male and female participants were 65.5 inches and 54.5 inches, respectively. Based on information provided directly by the manufacturers of the peak flow meters used, it was estimated that peak flow readings for these median heights should be around 370 L/min for male participants and 233 L/min for female participants. For the average peak flow readings recorded, median male peak flow was 290 L/min and median female peak flow was 223.3 L/min. Based on these findings, it can be seen that while female participants had peak flow rates that were relatively close to pediatric normal values, male participants had on average rates that were significantly lower.

A total of twenty three participants had sufficient data for analysis of the relationship between asthma risk and the presence of fly ash on the impactor filters; one participant was missing filter data and lift tape samples. Fourteen (51.85%) of these participants were diagnosed as having asthma based on their peak flow scores (Tables 3A and 3B) and thirteen (48.15%) of these participants were diagnosed as having asthma or suspected undiagnosed asthma based on their respiratory health questionnaire responses (Table 3C). A total of five participants (18.5%) had fly ash detected on impactor filters in their homes. Twenty one participants (81.5%) had fly ash detected on lift tape samples taken from their homes; five participants had fly ash detected on one lift tape sample, six participants had fly ash detected on two lift tape samples, and ten participants had fly ash detected on three lift tape samples (Table 3B).

As previously noted, two different methods were utilized to diagnose asthma including peak flow measurements and the asthma questionnaire. Neither outcome variables for asthma were found to be normally distributed; Anderson-Darling p-values were <0.0050. For each group of participants (asthma diagnosis by peak flow with regard to presence of fly ash on impactor filters, asthma diagnosis by peak flow with regard to presence of fly ash on lift tape samples, asthma diagnosis by questionnaire results with regard to presence of fly ash on impactor filters, and asthma diagnosis by questionnaire results with regard to presence of fly ash on lift tape samples) the Chi-Square and Fisher's Exact Test values were reported; given the small sample size, Fisher's Exact Test was the more appropriate.

Table 3A reports asthma diagnosis by whether fly ash was present or absent on the filters in the home. Among the 14 participants who were diagnosed with asthma via peak flow values, eight did not had asthma and did not had fly ash on the impactor filters, ten were diagnosed with asthma but did not had ash on the filters, one was not diagnosed with asthma but did had ash found on the filter, and four were diagnosed with asthma and had ash found on the filters. A Chi-Square value of 0.982 (p = 0.322, 1 degree of freedom) was determined, which was smaller than the critical value of 3.841 and therefore suggested no significant relationship between asthma diagnosis and fly ash presence. A Fisher's two-sided p-value of 0.611 was determined, again suggesting no significant relationship. Logistic regression was used to estimate both crude and adjusted odds ratios between asthma diagnosed by peak flow values and fly ash exposure; however, the small sample size did not allow for sufficient precision to interpret the results. Nevertheless, the crude odds ratio was determined to be 3.20 (95% CI = 0.296 – 34.6). For a model that adjusted for the presence of confounders, smoking in the home and lack of regular home air filter maintenance, an AOR of 4.339 (95% CI = 0.350 – 53.7) was determined.

Table 3A **Frequency of Asthma as Diagnosed by Peak Flow Values, Based on Presence of Coal Ash on Impactor Filters**				
	No Asthma	Asthma	Total	Chi Square
Ash Not Present	8	10	18	$X_2 = 0.982$, ($p=0.322$)
Ash Present	1	4	5	
Total	9	14	23	

Among those who were diagnosed via peak flow values (Table 3B), one participant was not diagnosed with asthma and had no lift tape samples with fly ash, three participants were not diagnosed with asthma but had one lift tape sample with fly ash, three participants were not diagnosed with asthma but had two lift tape samples with fly ash, and three participants were not diagnosed with asthma but had three lift tape samples with fly ash. Two participants were diagnosed with asthma but had no lift tape samples with fly ash, two participants were diagnosed with asthma and had one lift tape sample with fly ash, three participants were diagnosed with asthma and had two lift tape samples with fly ash, and seven participants were diagnosed with asthma and had three lift tape samples with fly ash. A Chi-Square value of 1.501 (p = 0.680, 3 degrees of freedom) was determined, which was less than the critical value of 7.815 and therefore suggested no significant relationship between asthma diagnosis and the presence of fly ash. Using logistic regression to establish a model that adjusted for the presence of smoking in the home and lack of regular home air filter maintenance, an AOR of <0.001 (95% CI = <.001 - >999.999) was determined for each quantity category of lift tape sample.

Table 3B **Frequency of Asthma as Diagnosed by Peak Flow Values, Based on Presence of Coal Ash on Lift Tape Samples**			
	No Asthma	Asthma	Total
Ash Not Present	1	2	3
One Sample	3	2	5
Two Samples	3	3	6
Three Samples	3	7	10
Total	10	14	24

Among those who were diagnosed via questionnaire results, ten participants were not diagnosed with asthma and did not had fly ash found on the impactor filters, eleven participants were diagnosed with asthma but did not had fly ash found on the impactor filters, three participants were not diagnosed with asthma but had fly ash found on the impactor filters, and two participants were diagnosed with asthma and had fly ash found on the impactor filters (Table 3C). A Chi-Square value of 0.248 (p = 0.619, 1 degree of freedom) was determined, which was less than the critical value of 3.841 and therefore suggested no significant relationship between asthma diagnosis and the presence of fly ash. A Fisher's two-sided p-value of 1.0000 was determined, again suggesting no significant relationship. Using logistic regression, a crude logistic model for the association of asthma diagnosis by questionnaire and fly ash on the filters was determined to be 0.606 (95% CI = 0.083 – 4.41). For a model that adjusted for gender, lack of regular home air filter maintenance, and self-perceived elevated levels of dust in the home, an AOR of 0.419 (95% CI = 0.046 – 3.811) was determined.

Table 3C **Frequency of Asthma as Diagnosed by Questionnaire Results, Based on Presence of Coal Ash on Impactor Filters**				
	No Asthma	Asthma	Total	Chi Square
Ash Not Present	10	11	21	X2 = 0.248, (p=0.500)
Ash Present	3	2	5	
Total	13	13	26	

Among those who were diagnosed via questionnaire results (Table 3D), one participant was not diagnosed with asthma and had no lift tape samples with fly ash, four participants were not diagnosed with asthma but had one lift tape sample with fly ash, two participants were not diagnosed with asthma but had two lift tape samples with fly ash, and six participants were not diagnosed with asthma but had three lift tape samples with fly ash. One participant was diagnosed with asthma but had no lift tape samples with fly ash, one participant was diagnosed with asthma and had one lift tape sample with fly ash, five participants were diagnosed with asthma and had two lift tape samples with fly ash, and four participants were diagnosed with asthma and had three lift tape samples with fly ash. A Chi-Square value of 3.34 (p = 0.342, 3 degrees of freedom) was determined, which was less than the critical value of 7.815 and therefore suggested no significant relationship between asthma diagnosis and the presence of fly ash. Using logistic regression, a crude odds ratio of 0.250 (95% CI = 0.007 – 8.56) was determined when one lift tape sample was found to had fly ash, a crude odds ratio of 2.50 (95% CI =

0.100 – 62.605) was determined when two lift samples were found to had fly ash, and a crude odds ratio of 0.667 (95% CI = 0.032 – 14.033) was determined when three lift tape samples were found to had fly ash. For a model that adjusted for gender, the presence of smoking in the home, and self-perceived elevated levels of dust in the home, an AOR of <.001 (95% CI = <0.001 - >999.999) was determined when one lift tape sample was found to had fly ash, an AOR of 7.449 (95% CI = 0.157 – 354.457) was determined when two lift tape samples were found to had fly ash, and an AOR of 0.662 (95% CI = 0.029 – 15.113) was determined when three lift tape samples were found to had fly ash.

Table 3D
Frequency of Asthma as Diagnosed by Questionnaire Results, Based on Presence of Coal Ash on Lift Tape Samples

	No Asthma	Asthma	Total
Ash Not Present	1	1	2
One Sample	4	1	5
Two Samples	2	5	7
Three Samples	6	4	10
Total	13	11	24

Aim Two

Twenty five of the twenty seven participants (92.59%) who provided data had sufficient data for analysis of the relationship between the presence of potentially toxic metals or metalloids found on the impactor filters and the risk of asthma. Boron, lead, and mercury were not detected on any of the filters, and were therefore not included in the analysis; arsenic, chromium, and manganese were detected. Of the participants that had sufficient data for this aim's analysis methods, nine had arsenic found in their homes, five had chromium found in their homes, and fifteen had manganese found in their homes. Five participants had none of these metals detected on their filters, thirteen participants had one metal detected, four participants had two of the metals detected, and two of the participants had all three metals detected. A metal score of one was attached to each participant for each of the three metals that were detected, cumulatively adding to no more than three.

For participants who were diagnosed based on peak flow values, frequency analysis determined a Chi-Square value of 4.3305 ($p = 0.2279$, 3 degrees of freedom), which was less than the Critical value of 7.815 and therefore suggested no significant relationship between asthma diagnosis and the metals present in the home. Crude ORs of 0.292 (95% CI = 0.025 – 3.372), 0.083 (95% CI = 0.004 – 1.945), and >999.999 (95% CI = <0.001 - >999.999) were determined for the presence of one of the metals, two of the metals, and three of the metals, respectively – the presence of none of the metals acting as a reference. A model adjusting for the presence of smoking in the home and for lack of regular home air filter maintenance was created using logistic regression, providing adjusted ORs of 0.273 (95% CI = 0.019 – 3.980), 0.050 (0.001 – 2.354), and >999.999 (95% CI = <0.001 - >999.999) for the presence of one of the metals, two of the metals, and three of the metals, respectively – the presence of none of the metals again acting as a reference.

For participants who were diagnosed based on questionnaire responses, frequency analysis determined a Chi-Square value of 1.1180 ($p = 0.7727$, 3 degrees of freedom), which again was less than the critical value of 7.815 and therefore suggested no significant relationship between asthma diagnosis and the metals present in the home. Using logistic regression, crude ORs of 1.750 (95% CI = 0.215 – 14.224), 0.500 (95% CI = 0.028 – 8.952), and 1.500 (95% CI = 0.055 – 40.633) were determined for the presence of one of the metals, two of the metals, and three of the metals, respectively – the presence of none of the metals acting as a reference. A model adjusting for the presence of smoking in the home and for lack of regular home air filter maintenance was created using logistic regression, providing adjusted ORs of 1.893 (95% CI = 0.218 – 16.469), 0.717 (95% CI = 0.033 – 15.793), and 1.869 (95% CI = 0.057 – 61.632) for the presence of one of the metals, two of the metals, and three of the metals, respectively – the presence of none of the metals again acting as a reference.

Aim Three

The following two maps (Figures 2 and 3) were created in order to visually depict the distribution of asthma and non-asthma participants within the study area. The locations of the Cane Run and Mill Creek power plants were included as well, so as to provide a frame of reference for asthma case distribution. The maps include only Jefferson County, which has been further subdivided into census tracts; exact street locations were not included in the maps so as to protect participant privacy. Each map depicts the distribution of asthma and non-asthma participants based on a specific asthma diagnosis technique – essentially, diagnosis via questionnaire and diagnosis via peak flow values.

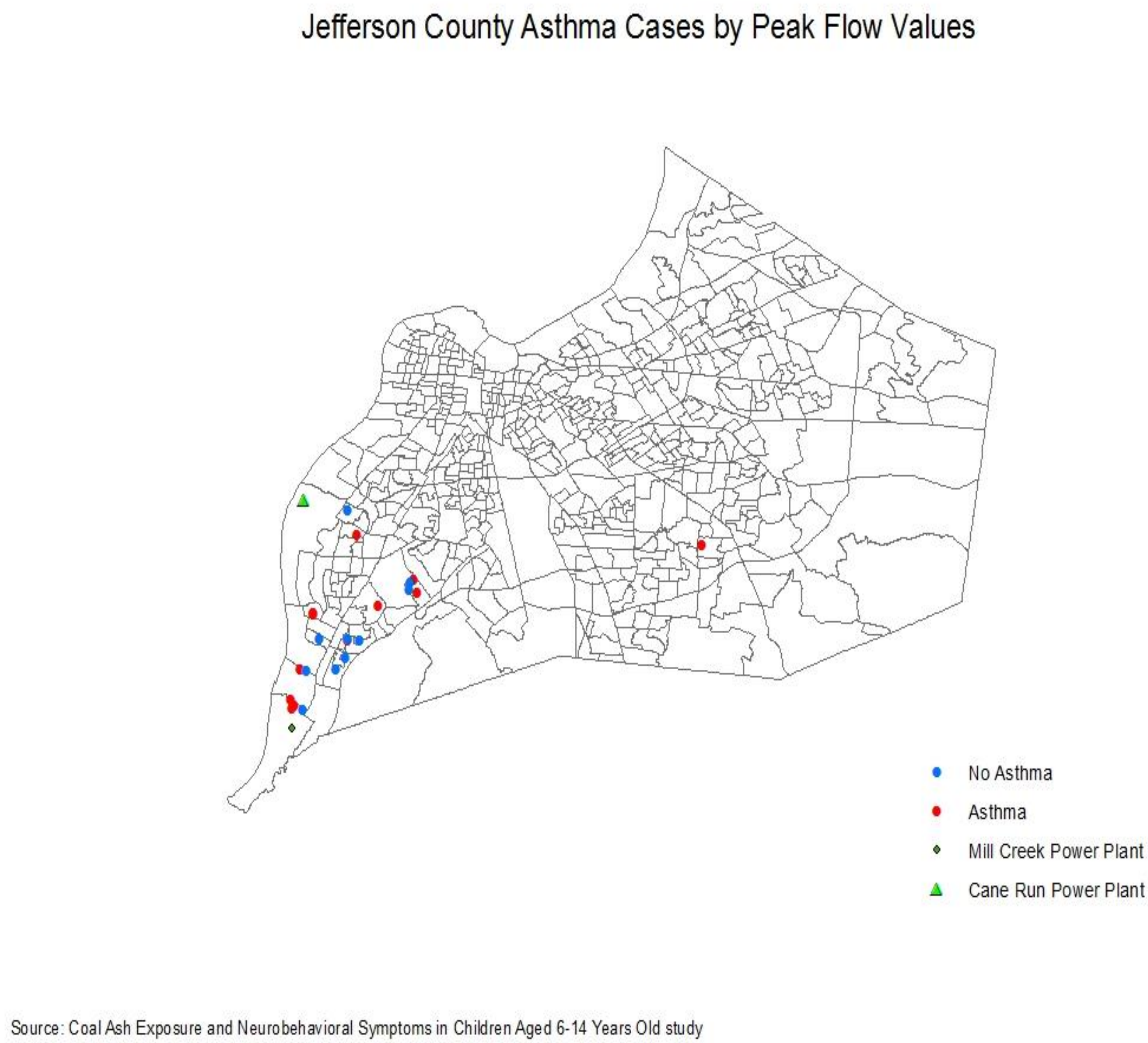
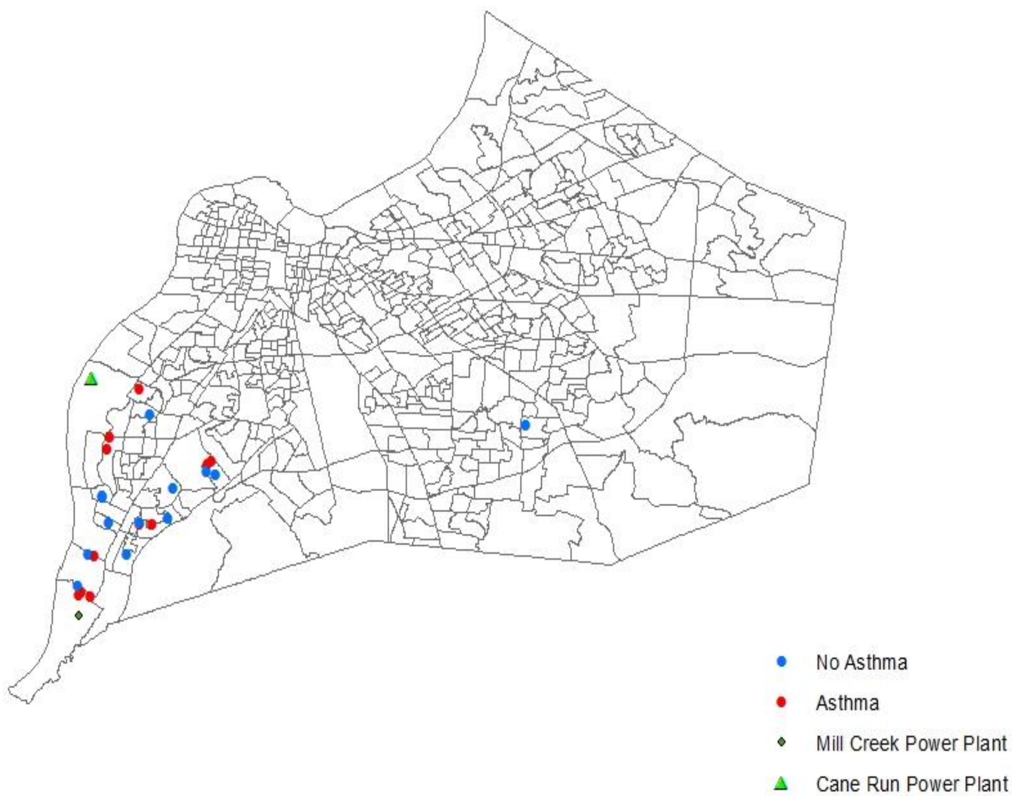


Figure 2 – Jefferson County Asthma Cases by Peak Flow Values

Jefferson County Asthma Cases by Questionnaire Results



Source: Coal Ash Exposure and Neurobehavioral Symptoms in Children Aged 6-14 Years Old study

Figure 3 – Jefferson County Asthma Cases by Questionnaire Results

The average distance from the Cane Run power plant for non-asthma participants based on peak flow data was 35,049.18 (95% CI = 31,061 – 39,037) feet, and the average distance from the Mill Creek power plant for non-asthma participants based on peak flow data was 31,146.81 (95% CI = 25,276 – 37,017) feet. The average distance from the Cane Run power plant for asthma-diagnosed participants based on peak flow data was 30,954.04 (95% CI = 23,343 – 38,565) feet, and the average distance from the Mill Creek power plant for asthma-diagnosed participants based on peak flow data was 22,959.86 (95% CI = 12,241 – 33,679) feet.

The average distance from the Cane Run power plant for non-asthma participants based on questionnaire data was 33,096.84 (95% CI = 26,312 – 39,882) feet, and the average distance from the Mill Creek power plant for non-asthma participants based on questionnaire data was 30,199.44 (95% CI = 21,200 – 39,199) feet. The average distance from the Cane Run power plant for asthma-diagnosed participants based on questionnaire data was 28,953.63 (95% CI = 23,615 – 34,293) feet, and the average distance from the Mill Creek power plant for asthma-diagnosed participants based on questionnaire data was 24,380.79 (95% CI = 17,495 – 31,267) feet.

The distance analysis based on data gathered using the ArcGIS "near" function indicated inconclusive results. The preliminary findings revealed the following crude odds ratios regarding the relationship between asthma and proximity to the power plants: 1.125 (95% CI = 0.175 – 7.244) for questionnaire derived asthma cases and proximity to Cane Run, 0.600 (95% CI = 0.111 – 3.245) for questionnaire derived asthma cases and proximity to Mill Creek, 0.333 (95% CI = 0.028 – 3.926) for peak flow derived asthma cases and proximity to Cane Run, and 1.143 (95% CI = 0.179 – 7.283) for peak flow derived asthma cases and proximity to Mill Creek.

The following age and sex adjusted odds ratios were calculated: 0.298 (95% CI = 0.023 – 3.841) for questionnaire derived asthma cases and proximity to Cane Run, 1.138 (95% CI = 0.151 – 8.558) for questionnaire derived asthma cases and proximity to Mill Creek, 0.298 (95% CI = 0.023 – 3.841) for peak flow derived asthma cases and proximity to Cane Run, and 1.138 (95% CI = 0.151 – 8.558) for peak flow derived asthma cases and proximity to Mill Creek.

ANOVA revealed F values of 0.59 (p = 0.4506) for peak flow derived asthma cases and proximity to Cane Run and 0.28 (p = 0.6006) for peak flow derived asthma cases and proximity to Mill Creek. ANOVA revealed F values of 0.48 (p = 0.4961) for questionnaire derived asthma cases and proximity to Cane Run and 0.56 (p = 0.4642) for questionnaire derived asthma cases and proximity to Mill Creek.

DISCUSSION

General Observations

This small sub-study is one of the first to examine the association between coal ash exposure and childhood asthma. There were several difficulties associated with the completion of this study, including difficulties associated with subject ascertainment and recruitment, a short time frame for completion of the sub-study, and the subsequent small sample size. However, there are a number of strengths associated with involvement in the initial design and fine-tuning of the methods for recruitment, data collection, specimen collection, and data analysis. The reassessment of methods helped to optimize efficiency for the larger parent study. The field work involved in this study was of great personal benefit as well, providing useful skills and knowledge that otherwise would not had been obtained. Though such things can be taught in a classroom setting to a certain extent, working with a field-oriented study such as this was essential in developing an understanding of just how much work – and the different kinds of work – was required to obtain the results that were desired. Seeing a study all the way through to completion was certainly no easy task.

No significant challenges were posed by the fact that all participants within the study were required to be children. Minor setbacks were related to nail collection methods such as nail biting habits and age of child, which reduced the amount of available sample. However, the majority of participants were able to provide sufficient nail samples for composition analysis.

Data Observations

The median heights for male and female participants were 65.5 inches and 54.5 inches, respectively. Based on information provided directly by the manufacturers (54) of the peak flow meters (Clement Clarke International), it was estimated that peak flow readings for these median heights should be around 370 L/min for male participants and 233 L/min for female participants. For the average peak flow readings recorded, median male peak flow was 290 L/min and median female peak flow was 223.3 L/min. Based on these findings, it can be seen that while female participants had peak flow rates that were relatively close to pediatric normal values, male participants had on average rates that were significantly lower.

Respiratory health questionnaire and peak flow asthma diagnosis results were quite interesting in that they revealed that asthma rates in the study population were quite a bit higher than was seen in the general population. Of the twenty four participants analyzed for asthma risk, 58.3% had asthma based on peak flow readings and 45.8% had asthma or suspected asthma based upon questionnaire results. The national average percentage of children with asthma is 8.6% (42). Though the sample size was small, this suggests the possibility that some factor in the study area was causing elevated asthma risk.

Initial findings from the analysis of proximity to coal ash sites and asthma risk were inconclusive. Though explicit patterns were difficult to establish due to small sample size, it appears based on calculated means that more of the asthma diagnosed participants were located closer to the power plants, while the more of the non-asthma diagnosed participants were located further. A small cluster of asthma cases is located close to the Mill Creek power plant as shown in Figures 2 and 3. ANOVA values were inconclusive.

Limitations

Examining the relationship between coal ash exposure and asthma prevalence in individuals living within the study area was a challenging process, requiring a variety of data gathered through numerous different means. Unfortunately, given the somewhat unpredictable nature of field data gathering, the number of participants whose data could be utilized for the Coal Ash Exposure and Asthma in Children portion of the study was rather small – less than thirty.

Of the participants who provided data for the study (n = 54), the first 27 could not be utilized for analysis, as the original study did not include the portion on asthma and therefore required the development of a new IRB. The remaining 27 participants were used for this stub-study analysis. Of these 27 participants, four had incomplete data; one lacked respiratory health questionnaire data, and three had no reported height and gender values, excluding them from analysis.

The overall number of participants included in the study at the time of this thesis completion was limited by certain factors. The winter months yielded few new participants, perhaps due to busy holiday schedules and general lack of interest. The initial implementation of mailing lists did help considerably to increase the number of participants, but even this seemed to had diminished results over time. A combination of door-to-door recruitment and mailing list usage has been re-implemented for the summer months, which will hopefully once more provide a large influx of participants.

Future Research

This was only a pilot study, but preliminary results reveal promise; even if coal ash was not behind the asthma cases diagnosed, the findings suggest that the study population may be at much greater risk for asthma than the general population. The study team has access to a limited number of additional peak flow meters that can be used to acquire data from participants beyond those that were included in this analysis, meaning that the existing pool of data will grow larger in the coming months. Given that a significant issue with analysis appears to be small sample size, adding additional participants could help to clarify and refine the results found.

Money for the purchasing of the peak flow meters used was not budgeted for in the Coal Ash Exposure and Neurobehavioral Symptoms in Children Aged 6-14 Years Old grant. Therefore only a limited number of peak flow meters could be purchased from another funding source, thus limiting the potential amount of data that could be collected on asthma in the study population. Given the promise of this study, it was hoped that a future grant expressly concerning these matters will be funded, allowing for greater examination of the relationship between asthma and coal ash in the study area.

REFERENCES

1. Leikauf GD. Hazardous Air Pollutants and Asthma. *Environmental Health Perspectives* 2002;110(4):505-26.
2. Alhanti BA, Chang HH, Winquist A, et al. Ambient air pollution and emergency department visits for asthma: a multi-city assessment of effect modification by age. *J Expo Sci Environ Epidemiol* 2016;26(2):180-8.
3. Wu TJ, Wu CF, Chen BY, et al. Age of asthma onset and vulnerability to ambient air pollution: an observational population-based study of adults from Southern Taiwan. *BMC Pulm Med* 2016;16(1):54.
4. Gottlieb B, al. e. Coal Ash: The Toxic Threat to Our Health and Environment. *Physicians for Social Responsibility* 2010:1-27.
5. Donaldson K, Gilmour MI, MacNee W. Asthma and PM10. *Respir Res* 2000;1(1):12-5.
6. Gerald LB, al. e. A Multi-Stage Asthma Screening Procedure for Elementary School Children. *Journal of Asthma* 2002;39(1):29-36.
7. Weinmayr G, Romeo E, De Sario M, et al. Short-term effects of PM10 and NO2 on respiratory health among children with asthma or asthma-like symptoms: a systematic review and meta-analysis. *Environ Health Perspect* 2010;118(4):449-57.
8. Sun Z, An X, Tao Y, et al. Assessment of population exposure to PM10 for respiratory disease in Lanzhou (China) and its health-related economic costs based on GIS. *BMC Public Health* 2013;13:891.
9. Association ACA. 2014 Final Survey Tables and Charts. 2014. (https://www.acaa-usa.org/Portals/9/Files/PDFs/2014ReportFinal.pdf). (Accessed).
10. LG&E. About LG&E. 2017. (https://lge-ku.com/our-company/about-lge). (Accessed).
11. EPA. Kentucky and Coal Ash Disposal in Ponds and Landfills. Earth Justice; 2009. (https://www.kftc.org/sites/default/files/docs/resources/ky-coal-ash-factsheet0811.pdf). (Accessed).
12. LG&E. History Cane Run Plant. 2017. (https://lge-ku.com/cane-run/history). (Accessed).
13. U.S. EO. Assessment of Dam Safety Coal Combustion Surface Impoundments (Task 3) Draft Report : Louisville Gas & Electric Company - Cane Run Power Station. 2009. (https://archive.epa.gov/epawaste/nonhaz/industrial/special/fossil/web/pdf/eon-cane-draft.pdf). (Accessed).
14. Dewan S. E.P.A. Lists "High Hazard" Coal Ash Dumps. The New York Times, 2009.
15. Bruggers J. LG&E to Cap Cane Run Coal Ash. The Courier Journal, 2015.
16. Peterson E. Cane Run Power Plant Neighbors Sue LG&E Over Coal Ash. wfpl.org: NPR; 2013. (http://wfpl.org/cane-run-power-plant-neighbors-sue-lge-over-coal-ash/). (Accessed).
17. LG&E. Mill Creek Generating Station. 2017. (https://lge-ku.com/our-company/community/neighbor-neighbor/mill-creek-generating-station). (Accessed).
18. EPA. LG&E Mill Creek Station Report. 2009.
19. Holm JW. CCR Rule Annual Inspection Report - Louisville Gas and Electric Mill Creek Landfill. . 2016.

20. LG&E. Press Release: Utility to Close Ash Ponds at Mill Creek and Trimble County Generating Stations. 2016. (https://lge-ku.com/newsroom/press-releases/2016/01/11/lge-invest-more-300-million-additional-environmental-improvements). (Accessed).
21. Zeneli L, Sekovanic A, Ajvazi M, et al. Alterations in Antioxidant Defense System of Workers Chronically Exposed to Arsenic, Cadmium and Mercury from Coal Flying Ash. *Environmental and Geochemical Health* 2015.
22. Group RL. Surface Dust Study, RJ Lee Group Project Number: TLH104154. RJ Lee GRoup, 2011.
23. Borm PJA. Toxicity and Occupational Health Hazards of Coal Fly Ash (CFA). A Review of Data and Comparison to Coal Mine Dust. *Annals of Occupational Hygiene* 1997;41(6):659-76.
24. Davison A. Asthma Caused by Pulverised Fuel Ash. *British Medical Journal* 1986;292:1561.
25. Leikauf GD. Hazardous Air Pollutants and Asthma. *Environmental Health Perspectives* 2002;110(4):505-26.
26. George J, Masto RE, Ram LC, et al. Human Exposure Risks for Metals in Soil Near a Coal-Fired Power-Generating Plant. *Archives of Environmental Contamination and Toxicology* 2014;68:451-61.
27. Abdul KS, Jayasinghe SS, Chandana EP, et al. Arsenic and human health effects: A review. *Environ Toxicol Pharmacol* 2015;40(3):828-46.
28. Parvez F, Chen Y, Brandt-Rauf PW, et al. A prospective study of respiratory symptoms associated with chronic arsenic exposure in Bangladesh: findings from the Health Effects of Arsenic Longitudinal Study (HEALS). *Thorax* 2010;65(6):528-33.
29. Beaver LM, Stemmy EJ, Constant SL, et al. Lung injury, inflammation and Akt signaling following inhalation of particulate hexavalent chromium. *Toxicol Appl Pharmacol* 2009;235(1):47-56.
30. Tolot F, Broudeur P, Neulat G. [Asthmatic forms of lung diseases in workers exposed to chromium, nickel and aniline inhalation]. *Arch Mal Prof* 1957;18(3):291-3.
31. Registry AfTSD. ToxFAQs for Chromium. CDC; 2016. (https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=61&tid=17#bookmark06). (Accessed).
32. Cerveira JF, Sanchez-Arago M, Urbano AM, et al. Short-term exposure of nontumorigenic human bronchial epithelial cells to carcinogenic chromium(VI) compromises their respiratory capacity and alters their bioenergetic signature. *FEBS Open Bio* 2014;4:594-601.
33. Registry AfTSD. Tox FAQs for Boron. CDC; 2011. (https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=452&tid=80#bookmark06). (Accessed).
34. Registry AfTSD. ToxFAQs for Manganese. CDC; 2014. (https://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=101&tid=23#bookmark05). (Accessed).
35. Han J, Lee JS, Choi D, et al. Manganese (II) induces chemical hypoxia by inhibiting HIF-prolyl hydroxylase: implication in manganese-induced pulmonary inflammation. *Toxicol Appl Pharmacol* 2009;235(3):261-7.
36. Nielsen FH. Update on human health effects of boron. *J Trace Elem Med Biol* 2014;28(4):383-7.
37. Mastromatteo E, Sullivan F. Summary: International Symposium on the Health Effects of Boron and its Compounds. *Environ Health Perspect* 1994;102 Suppl 7:139-41.
38. Carocci A, Rovito N, Sinicropi MS, et al. Mercury toxicity and neurodegenerative effects. *Rev Environ Contam Toxicol* 2014;229:1-18.

39. Registry AfTSD. ToxFAQs for Mercury. CDC; 2015. (https://www.atsdr.cdc.gov/toxfaqs/TF.asp?id=113&tid=24#bookmark05). (Accessed).
40. Lien DC, Todoruk DN, Rajani HR, et al. Accidental inhalation of mercury vapour: respiratory and toxicologic consequences. *Can Med Assoc J* 1983;129(6):591-5.
41. Flora G, Gupta D, Tiwari A. Toxicity of lead: A review with recent updates. *Interdiscip Toxicol* 2012;5(2):47-58.
42. Statistics NCfH. Asthma. CDC; 2016. (http://www.cdc.gov/nchs/fastats/asthma.htm). (Accessed).
43. Gorai AK, Tuluri F, Tchounwou PB. A GIS based approach for assessing the association between air pollution and asthma in New York State, USA. *Int J Environ Res Public Health* 2014;11(5):4845-69.
44. Hanchette C, Lee J-H, Aldrich TE. Childhod Asthma and Air Quality in Louisville, Kentucky. 2012.
45. Louis GB, Damstra T, Diaz-Barriga F, et al. Principles for Evaluating Health Risks in Children Associated with Exposure to Chemicals. *Environmental Health Criteria*: World Health Organization, 2006:1-351.
46. M. L. The Hazards of Air Pollution to Children. *Environmental Medicine* 1995.
47. Etzel RA. Air Pollution Hazards to Children. *Otolaryngology - Head and Neck Surgery* 1996;114(2):265-6.
48. Vine MF, Degnan D, Hanchette C. Geographic information systems: their use in environmental epidemiologic research. *Environ Health Perspect* 1997;105(6):598-605.
49. Gerald LB, Grad R, Turner-Henson A, et al. Validation of a multistage asthma case-detection procedure for elementary school children. *Pediatrics* 2004;114(4):e459-68.
50. Manjunath C, Kotinatot S, Manjunatha B. Peak Expiratory Flow Rate in Healthy Rural School Going Children (5-16 Years) of Bellur Region for Construction of Nomogram. *Journal of Clinical and Diagnostic Research* 2013;7(12):2844-6.
51. Sharat G, Shallu M, Avnish K, et al. Peak Expiratory Flow Rate of Healthy School Children Living at High Altitude. *North American Journal of Medical Sciences* 2013;5(7):422-6.
52. Incorporated EA. Proton Induced X-ray Emission (PIXE). 2016. (http://www.elementalanalysis.com/services/proton-induced-x-ray-emission-pixe/). (Accessed).
53. Swapp S. Scanning Electron Microscopy (SEM). University of Wyoming; 2015. (http://serc.carleton.edu/research_education/geochemsheets/techniques/SEM.html). (Accessed).
54. International CC. Paediatric Normal Values. Essex, England. (http://www.peakflow.com/paediatric_normal_values.pdf). (Accessed).
55. Woodward M. *Epidemiology: Study Design and Data Analysis*. Third Edition ed. Boca Raton, London, New York: CRC Press; 2014.

APPENDIX A

Respiratory Health Questionnaire

University of Louisville
School of Public Health and Information Sciences
Child Respiratory Health Questionnaire

Name of Child (*first, middle, last*):

Child's Date of Birth:

Today's Date:

Please fill in the circles completely. Thank you for answering

1) Has your child ever had a cough that would not go away or ever seemed to be coughing more than other children of the same age?

Yes	(A)
No	(B)

2) Has your child ever had wheezing?

Yes	(A)
No	(B)

3) Has your child ever had to stop running or playing because of coughing or wheezing?

Yes	(A)
No	(B)

4) Has your child ever said his/her chest felt tight or heavy or that his/her chest hurt?

Yes	(A)
No	(B)

5) Has your child ever had breathing problems (coughing, wheezing, shortness of breath, chest tightness) that woke him/her up at night?

Yes	(A)
No	(B)

6) Has your child ever had breathing problems (coughing, wheezing, shortness of breath, chest tightness) when he/she first woke up in the morning?

Yes	(A)
No	(B)

7) Has a doctor ever said your child has **asthma**?

Yes	(A)
No	(B)

8) Dose your child take **asthma medication** prescribed by a doctor daily or even occasionally?

Yes	(A)
No	(B)

9) Has a doctor ever said your child had **bronchiolitis**?

Yes	(A)
No	(B)

10) Has a doctor ever said your child had **bronchitis**?

Yes	(A)
No	(B)

11) Has a doctor ever said your child had **asthmatic bronchitis**?

Yes	(A)
No	(B)

12) Has a doctor ever said your child had **pneumonia** (more than one time)?

Yes	(A)
No	(B)

13) Is your child regularly exposed to smoke (as from cigarettes, pipe tobacco, or any other smoked substance) in the home?

Yes	(A)
No	(B)

14) Are the air conditioning filters in your home changed as recommended by the manufacturer (this is generally every four to six weeks)?

Yes	(A)
No	(B)

15) Does your home seem dustier than friends or family who do not live in the area?

Yes	(A)
No	(B)

CURRICULUM VITAE

Contact Information

Name:

- Jack Pfeiffer

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- 409 Lindsay Court, Apt. 8, Louisville, KY 40206

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Education

University of Louisville

- 2011-2014
  - BA (Honors) in Biological Anthropology
  - Subjects included human evolution, evolutionary ecology of disease, general ecology, genetics, cellular/molecular biology, medical anthropology
- 2014-2017
  - MS in Epidemiology
  - Thesis concentration in environmental epidemiology – the relationship between coal fly ash exposure and asthma in children
  - Subjects included Maternal/Child Epidemiology, Nutritional Epidemiology, Epidemiology Methods, Epidemiological Research Management, Biostatistics Foundations, Population Pathology, and GIS and Public Health
  - GPA: 3.930

Professional Experience

The White Squirrel September 2011-May 2014

Volunteer Editor

Louisville, KY

- Assisted in management of the University's student-run literary arts magazine.
- Contacted local businesses and helped manage sales and distribution of magazine.

The University of Louisville September 2013-December 2013
Intern – MAPS Laboratory
Louisville, KY

- Learned basic laboratory techniques and methods such as gel electrophoresis, DNA extraction, and PCR.
- Increased familiarity with various types of laboratory equipment.

The University of Louisville, Department of Public Health August 2015-August 2016
Volunteer Researcher – Coal Ash Exposure and Neurobehavioral Symptoms in Children study
Louisville, KY

- Recruit participants through mailing lists and door-to-door distribution of flyers.
- Gather participant data through the use of various environmental monitoring technologies.
- Process and analyze participant data.

St. Matthews Community Pharmacy August 2016-present
Certified Pharmacy Technician
Louisville, KY
Manager of Merchandising and Social Media

- Maintain patient prescription information, fill patient prescriptions, and resolve conflicts relating to patient prescriptions on file
- Communicate with insurance companies to resolve patient prescription complications
- Handle most pharmacy merchandising functions, including management of key over the counter product lines
- Utilize Rx30 software for a variety of pharmacy functions
- Communicate pharmacy and health related news and articles via use of company social media page

Activities and Interests

- Former Treasurer of the Louisville Film Club
- Former Editor and Co-Editor in Chief of the *White Squirrel* UofL literary magazine
- Former volunteer at the University of Louisville Department of Infectious Disease

Skills

Technical: Proficient in Microsoft Word, Excel, PowerPoint, and in navigation of the Internet. Working knowledge of SAS. OSHA and Laboratory Safety certified. Working knowledge of GIS for public health purposes.
Writing: Extensive knowledge of academic writing and reading. Excellent grammar skills.
Presentation: Strong public-speaking skills and familiarity with speaking in front of groups.